

"Express Mail" mailing label number:

EL 830059338 US

**TRANSPORT OF HIGH-BANDWIDTH DATASTREAMS OVER A
NETWORK**

Rajendra R. Damle
Young Lee
William C. Szeto
Robert Keith Butler
H. Michael Zadikian

5

CROSS-REFERENCES TO RELATED APPLICATIONS

The present invention claims priority from:

- 10 1. Provisional Patent Application Serial No. 60/268,237, entitled "EVOLUTION
OF CARRRIER BACKBONE DATA NETWORK NEW
REQUIREMENTS", filed February 12, 2001, and naming R. R. Damle as
inventor;
- 15 2. Provisional Patent Application Serial No. 60/268,180, entitled "END-TO-
END NETWORK ARCHITECTURE FOR THE NEXT GENERATION IP
NETWORK", filed February 12, 2001, and naming R. K. Butler as inventor;
3. Provisional Patent Application Serial No. 60/287,973, entitled "METHOD
AND APPARATUS FOR LONG-HAUL OPTICAL NETWORKING", filed
April 30, 2001, and naming R. K. Butler as inventor; and
- 20 4. Provisional Patent Application Serial No. 60/295,645, entitled "TRANSPORT
OF HIGH-BANDWIDTH DATASTREAMS OVER A NETWORK", filed
June 4, 2001, and naming R. Damle, Y. Lee, W. Szeto, R. Butler and H. M.
Zadikian as inventors.

25 Applicants hereby claim the benefit under 35 U.S.C. §119(e) of the foregoing-
referenced provisional patent applications. The foregoing-referenced provisional
patent applications are hereby incorporated by reference herein, in their entirety and
for all purposes.

BACKGROUND OF THE INVENTION**Field of the Invention**

This invention relates to the field of information networks, and more particularly relates to a method and system for transporting information over a network.

5

Description of the Related Art

Today's networks carry vast amounts of information. High bandwidth applications supported by these networks include streaming video, streaming audio, and large aggregations of voice traffic. In the future, these demands are certain to increase. To meet such demands, an increasingly popular alternative is the use of lightwave communications carried over fiber-optic cables. The use of lightwave communications provides several benefits, including high bandwidth, ease of installation, and capacity for future growth.

In an optical network, the data is transmitted between network elements (also referred to as data sources and/or sinks) over one or more communications links (or more simply, links), at least in part via an optical carrier. A general example of such a network is one in which a first network element and a second network element (e.g., optical switches or routers), both of which process and transmit data local to themselves, employ an underlying optical network to transport information from one to the other. Such an optical network provides for the transmission of data between the first network element and the second network element at least in part by use of optical carriers traversing optical fiber(s) that span the distance between network elements. A more specific example of an optical network is a network in which network components employ the SONET (Synchronous Optical NETwork) protocol.

20

The SONET protocol is one of a number of protocols employing an optical infrastructure. SONET is a physical transmission vehicle capable of transmission speeds in the multi-gigabit range, and is defined by a set of electrical as well as optical standards. SONET's ability to use currently-installed fiber-optic cabling, coupled with the fact that SONET significantly reduces complexity and equipment functionality

10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
405
410
415
420
425
430
435
440
445
450
455
460
465
470
475
480
485
490
495
500
505
510
515
520
525
530
535
540
545
550
555
560
565
570
575
580
585
590
595
600
605
610
615
620
625
630
635
640
645
650
655
660
665
670
675
680
685
690
695
700
705
710
715
720
725
730
735
740
745
750
755
760
765
770
775
780
785
790
795
800
805
810
815
820
825
830
835
840
845
850
855
860
865
870
875
880
885
890
895
900
905
910
915
920
925
930
935
940
945
950
955
960
965
970
975
980
985
990
995
1000
1005
1010
1015
1020
1025
1030
1035
1040
1045
1050
1055
1060
1065
1070
1075
1080
1085
1090
1095
1100
1105
1110
1115
1120
1125
1130
1135
1140
1145
1150
1155
1160
1165
1170
1175
1180
1185
1190
1195
1200
1205
1210
1215
1220
1225
1230
1235
1240
1245
1250
1255
1260
1265
1270
1275
1280
1285
1290
1295
1300
1305
1310
1315
1320
1325
1330
1335
1340
1345
1350
1355
1360
1365
1370
1375
1380
1385
1390
1395
1400
1405
1410
1415
1420
1425
1430
1435
1440
1445
1450
1455
1460
1465
1470
1475
1480
1485
1490
1495
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
1550
1555
1560
1565
1570
1575
1580
1585
1590
1595
1600
1605
1610
1615
1620
1625
1630
1635
1640
1645
1650
1655
1660
1665
1670
1675
1680
1685
1690
1695
1700
1705
1710
1715
1720
1725
1730
1735
1740
1745
1750
1755
1760
1765
1770
1775
1780
1785
1790
1795
1800
1805
1810
1815
1820
1825
1830
1835
1840
1845
1850
1855
1860
1865
1870
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
2105
2110
2115
2120
2125
2130
2135
2140
2145
2150
2155
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
2225
2230
2235
2240
2245
2250
2255
2260
2265
2270
2275
2280
2285
2290
2295
2300
2305
2310
2315
2320
2325
2330
2335
2340
2345
2350
2355
2360
2365
2370
2375
2380
2385
2390
2395
2400
2405
2410
2415
2420
2425
2430
2435
2440
2445
2450
2455
2460
2465
2470
2475
2480
2485
2490
2495
2500
2505
2510
2515
2520
2525
2530
2535
2540
2545
2550
2555
2560
2565
2570
2575
2580
2585
2590
2595
2600
2605
2610
2615
2620
2625
2630
2635
2640
2645
2650
2655
2660
2665
2670
2675
2680
2685
2690
2695
2700
2705
2710
2715
2720
2725
2730
2735
2740
2745
2750
2755
2760
2765
2770
2775
2780
2785
2790
2795
2800
2805
2810
2815
2820
2825
2830
2835
2840
2845
2850
2855
2860
2865
2870
2875
2880
2885
2890
2895
2900
2905
2910
2915
2920
2925
2930
2935
2940
2945
2950
2955
2960
2965
2970
2975
2980
2985
2990
2995
3000
3005
3010
3015
3020
3025
3030
3035
3040
3045
3050
3055
3060
3065
3070
3075
3080
3085
3090
3095
3100
3105
3110
3115
3120
3125
3130
3135
3140
3145
3150
3155
3160
3165
3170
3175
3180
3185
3190
3195
3200
3205
3210
3215
3220
3225
3230
3235
3240
3245
3250
3255
3260
3265
3270
3275
3280
3285
3290
3295
3300
3305
3310
3315
3320
3325
3330
3335
3340
3345
3350
3355
3360
3365
3370
3375
3380
3385
3390
3395
3400
3405
3410
3415
3420
3425
3430
3435
3440
3445
3450
3455
3460
3465
3470
3475
3480
3485
3490
3495
3500
3505
3510
3515
3520
3525
3530
3535
3540
3545
3550
3555
3560
3565
3570
3575
3580
3585
3590
3595
3600
3605
3610
3615
3620
3625
3630
3635
3640
3645
3650
3655
3660
3665
3670
3675
3680
3685
3690
3695
3700
3705
3710
3715
3720
3725
3730
3735
3740
3745
3750
3755
3760
3765
3770
3775
3780
3785
3790
3795
3800
3805
3810
3815
3820
3825
3830
3835
3840
3845
3850
3855
3860
3865
3870
3875
3880
3885
3890
3895
3900
3905
3910
3915
3920
3925
3930
3935
3940
3945
3950
3955
3960
3965
3970
3975
3980
3985
3990
3995
4000
4005
4010
4015
4020
4025
4030
4035
4040
4045
4050
4055
4060
4065
4070
4075
4080
4085
4090
4095
4100
4105
4110
4115
4120
4125
4130
4135
4140
4145
4150
4155
4160
4165
4170
4175
4180
4185
4190
4195
4200
4205
4210
4215
4220
4225
4230
4235
4240
4245
4250
4255
4260
4265
4270
4275
4280
4285
4290
4295
4300
4305
4310
4315
4320
4325
4330
4335
4340
4345
4350
4355
4360
4365
4370
4375
4380
4385
4390
4395
4400
4405
4410
4415
4420
4425
4430
4435
4440
4445
4450
4455
4460
4465
4470
4475
4480
4485
4490
4495
4500
4505
4510
4515
4520
4525
4530
4535
4540
4545
4550
4555
4560
4565
4570
4575
4580
4585
4590
4595
4600
4605
4610
4615
4620
4625
4630
4635
4640
4645
4650
4655
4660
4665
4670
4675
4680
4685
4690
4695
4700
4705
4710
4715
4720
4725
4730
4735
4740
4745
4750
4755
4760
4765
4770
4775
4780
4785
4790
4795
4800
4805
4810
4815
4820
4825
4830
4835
4840
4845
4850
4855
4860
4865
4870
4875
4880
4885
4890
4895
4900
4905
4910
4915
4920
4925
4930
4935
4940
4945
4950
4955
4960
4965
4970
4975
4980
4985
4990
4995
5000
5005
5010
5015
5020
5025
5030
5035
5040
5045
5050
5055
5060
5065
5070
5075
5080
5085
5090
5095
5100
5105
5110
5115
5120
5125
5130
5135
5140
5145
5150
5155
5160
5165
5170
5175
5180
5185
5190
5195
5200
5205
5210
5215
5220
5225
5230
5235
5240
5245
5250
5255
5260
5265
5270
5275
5280
5285
5290
5295
5300
5305
5310
5315
5320
5325
5330
5335
5340
5345
5350
5355
5360
5365
5370
5375
5380
5385
5390
5395
5400
5405
5410
5415
5420
5425
5430
5435
5440
5445
5450
5455
5460
5465
5470
5475
5480
5485
5490
5495
5500
5505
5510
5515
5520
5525
5530
5535
5540
5545
5550
5555
5560
5565
5570
5575
5580
5585
5590
5595
5600
5605
5610
5615
5620
5625
5630
5635
5640
5645
5650
5655
5660
5665
5670
5675
5680
5685
5690
5695
5700
5705
5710
5715
5720
5725
5730
5735
5740
5745
5750
5755
5760
5765
5770
5775
5780
5785
5790
5795
5800
5805
5810
5815
5820
5825
5830
5835
5840
5845
5850
5855
5860
5865
5870
5875
5880
5885
5890
5895
5900
5905
5910
5915
5920
5925
5930
5935
5940
5945
5950
5955
5960
5965
5970
5975
5980
5985
5990
5995
6000
6005
6010
6015
6020
6025
6030
6035
6040
6045
6050
6055
6060
6065
6070
6075
6080
6085
6090
6095
6100
6105
6110
6115
6120
6125
6130
6135
6140
6145
6150
6155
6160
6165
6170
6175
6180
6185
6190
6195
6200
6205
6210
6215
6220
6225
6230
6235
6240
6245
6250
6255
6260
6265
6270
6275
6280
6285
6290
6295
6300
6305
6310
6315
6320
6325
6330
6335
6340
6345
6350
6355
6360
6365
6370
6375
6380
6385
6390
6395
6400
6405
6410
6415
6420
6425
6430
6435
6440
6445
6450
6455
6460
6465
6470
6475
6480
6485
6490
6495
6500
6505
6510
6515
6520
6525
6530
6535
6540
6545
6550
6555
6560
6565
6570
6575
6580
6585
6590
6595
6600
6605
6610
6615
6620
6625
6630
6635
6640
6645
6650
6655
6660
6665
6670
6675
6680
6685
6690
6695
6700
6705
6710
6715
6720
6725
6730
6735
6740
6745
6750
6755
6760
6765
6770
6775
6780
6785
6790
6795
6800
6805
6810
6815
6820
6825
6830
6835
6840
6845
6850
6855
6860
6865
6870
6875
6880
6885
6890
6895
6900
6905
6910
6915
6920
6925
6930
6935
6940
6945
6950
6955
6960
6965
6970
6975
6980
6985
6990
6995
7000
7005
7010
7015
7020
7025
7030
7035
7040
7045
7050
7055
7060
7065
7070
7075
7080
7085
7090
7095
7100
7105
7110
7115
7120
7125
7130
7135
7140
7145
7150
7155
7160
7165
7170
7175
7180
7185
7190
7195
7200
7205
7210
7215
7220
7225
7230
7235
7240
7245
7250
7255
7260
7265
7270
7275
7280
7285
7290
7295
7300
7305
7310
7315
7320
7325
7330
7335
7340
7345
7350
7355
7360
7365
7370
7375
7380
7385
7390
7395
7400
7405
7410
7415
7420
7425
7430
7435
7440
7445
7450
7455
7460
7465
7470
7475
7480
7485
7490
7495
7500
7505
7510
7515
7520
7525
7530
7535
7540
7545
7550
7555
7560
7565
7570
7575
7580
7585
7590
7595
7600
7605
7610
7615
7620
7625
7630
7635
7640
7645
7650
7655
7660
7665
7670
7675
7680
7685
7690
7695
7700
7705
7710
7715
7720
7725
7730
7735
7740
7745
7750
7755
7760
7765
7770
7775
7780
7785
7790
7795
7800
7805
7810
7815
7820
7825
7830
7835
7840
7845
7850
7855
7860
7865
7870
7875
7880
7885
7890
7895
7900
7905
7910
7915
7920
7925
7930
7935
7940
7945
7950
7955
7960
7965
7970
7975
7980
7985
7990
7995
8000
8005
8010
8015
8020
8025
8030
8035
8040
8045
8050
8055
8060
8065
8070
8075
8080
8085
8090
8095
8100
8105
8110
8115
8120
8125
8130
8135
8140
8145
8150
8155
8160
8165
8170
8175
8180
8185
8190
8195
8200
8205
8210
8215
8220
8225
8230
8235
8240
8245
8250
8255
8260
8265
8270
8275
8280
8285
8290
8295
8300
8305
8310
8315
8320
8325
8330
8335
8340
8345
8350
8355
8360
8365
8370
8375
8380
8385
8390
8395
8400
8405
8410
8415
8420
8425
8430
8435
8440
8445
8450
8455
8460
8465
8470
8475
8480
8485
8490
8495
8500
8505
8510
8515
8520
8525
8530
8535
8540
8545
8550
8555
8560
8565
8570
8575
8580
8585
8590
8595
8600
8605
8610
8615
8620
8625
8630
8635
8640
8645
8650
8655
8660
8665
8670
8675
8680
8685
8690
8695
8700
8705
8710
8715
8720
8725
8730
8735
8740
8745
8750
8755
8760
8765
8770
8775
8780
8785
8790
8795
8800
8805
8810
8815
8820
8825
8830
8835
8840
8845
8850
8855
8860
8865
8870
8875
8880
8885
8890
8895
8900
8905
8910
8915
8920
8925
8930
8935
8940
8945
8950
8955
8960
8965
8970
8975
8980
8985
8990
8995
9000
9005
9010
9015
9020
9025
9030
9035
9040
9045
9050
9055
9060
9065
9070
9075
9080
9085
9090
9095
9100
9105
9110
9115
9120
9125
9130
9135
9140
9145
9150
9155
9160
9165
9170
9175
9180
9185
9190
9195
9200
9205
9210
9215
9220
9225
9230
9235
9240
9245
9250
9255
9260
9265
9270
9275
9280
9285
9290
9295
9300
9305
9310
9315
9320
9325
9330
9335
9340
9345
9350
9355
9360
9365
9370
9375
9380
9385
9390
9395
9400
9405
9410
9415
9420
9425
9430
9435
9440
9445
9450
9455
9460
9465
9470
9475
9480
9485
9490
9495
9500
9505
9510
9515
9520
9525
9530
9535
9540
9545
9550
9555
9560
9565
9570
9575
9580
9585
9590
9595
9600
9605
9610
9615
9620
9625
9630
9635
9640
9645
9650
9655
9660
9665
9670
9675
9680
9685
9690
9695
9700
9705
9710
9715
9720
9725
9730
9735
9740
9745
9750
9755
9760
9765
9770
9775
9780
9785
9790
9795
9800
9805
9810
9815
9820
9825
9830
9835
9840
9845
9850
9855
9860
9865
9870
9875
9880
9885
9

requirements, gives local and interexchange carriers incentive to employ SONET. Also attractive is the immediate savings in operational cost that this reduction in complexity provides. SONET thus allows the realization of a new generation of high-bandwidth services in a more economical manner than previously existed.

5 However, as the need for throughput continues to increase, even optical networks can be strained. One solution is the use of wavelength division multiplexing (WDM). In WDM systems, a number of wavelengths are used to transport the information. Further demands on the optical infrastructure can be met by increasing the data rate carried on each wavelength. This solution is not without problems.

10 Increasing the data rate carried on each wavelength can require newer, costly components that are designed for the higher data rates (including sophisticated modulators/receivers, newer fibers and the like). In fact, such an alternative does not necessarily provide greater total capacity per fiber (e.g., in the case of higher bit-error rates (BER)). Higher transmission rates can also limit transmission distance (due to the reduced ability to handle errors and the increased likelihood of same), and likely require more signal regeneration to overcome such problems, as well as the use of additional TDM devices. Thus, such a solution may not be well-suited to long-haul optical networking objectives (low cost, high throughput, and so on), and likely involves an increased cost per bit transmitted.

15 Of course, the number of wavelengths may be increased, within the capabilities of the optical technology employed. However, this can greatly complicate the management of such an optical network. For example, the complexity of an optical cross-connect increases on the order of the square of the number of entities (e.g., wavelengths) being switched. Thus, as wavelengths are added, the complexity 20 of such a device increases dramatically.

25 Fig. 1 is a block diagram illustrating a network in which optical transport is employed to provide communications (e.g., data communications) between network elements 100 and 101. Network elements 100 and 101 include protocol processors 102 and 103, which provide a standard protocol stack that ensures that the information 30 being transported is appropriately processed and routed. Protocol processors 102 and

103 operate, for example, in the electrical domain and handle high-speed datastreams
104(1)-(N) and 106(1)-(N), respectively, which are themselves in the electrical
domain. Ports 108 and 110 interface electrical-optical converters 112 and 114 with
protocol processors 102 and 103 by transmitting/receiving high-speed datastreams
5 104(1)-(N) and 106(1)-(N) to/from protocol processors 102 and 103. Those skilled in
the art will appreciate that while each of electrical-optical converters 112 and 114 is
depicted as having only one electrical port for simplicity, several such ports, and such
ports' attendant connections with their respective protocol processors, typically exist.
Those skilled in the art will also recognize that other transmission schemes can be
10 utilized to move data between protocol processors 102 and 103, and ports 108 and
110, some of which are optical (however, for the sake of clarity such other
transmission schemes are not addressed in the present discussion).

In operation, electrical-optical converters 112 and 114 convert high-speed
datastreams 104(1)-(N) and 106(1)-(N) between the electrical and optical domains.
15 The SONET protocol, in large part, defines interfaces, standards, and interactions for
optical-electrical converters 112 and 114, such that each electrical-domain high-speed
datastream of high-speed datastreams 104(1)-(N) and 106(1)-(N) corresponds to a
datastream in the optical domain (i.e., is transmitted via an optical carrier over one of
optical channels 115(1)-(N)) and vice versa.

20 As Fig. 1 shows, optical port groups 116 and 118 interface with optical fiber(s)
120. The term "optical port groups" is used because, in practice, each of optical
channels 115(1)-(N) will have an associated optical port in both of electrical
converters 112 and 114. The term "optical fiber(s)" is used due to the fact that, in
practice, each of optical channels 115(1)-(N) may be transported mono-modally (i.e.,
25 via light (of a given wavelength) travelling over a mono-modal fiber), multi-modally
(i.e., via light having one of a number of wavelengths traveling over a multi-modal
fiber), or a combination thereof (i.e., via wavelengths dispersed across some
combination of mono-modal and multi-modal fibers).

It will be noted that the variable identifier "N" is used in several instances in
30 Fig. 1 to more simply designate the final element (e.g., high-speed datastreams

104(1)-(N) and 106(1)-(N), optical channels 115(1)-(N) and so on) of a series of related or similar elements (e.g., high-speed datastreams, optical channels and so on). The repeated use of such variable identifiers is not meant to imply a correlation between the sizes of such series of elements, although such correlation may exist. The
5 use of such variable identifiers does not require that each series of elements has the same number of elements as another series delimited by the same variable identifier. Rather, in each instance of use, the variable identified by "N" may hold the same or a different value than other instances of the same variable identifier.

Fig. 1 also illustrates that portions of electrical-optical converters 112 and 114 and optical fiber(s) 120, as well as such components' associated ports, can be viewed as an underlying network infrastructure, or (as is the case in an optical network such as that depicted in Fig. 1, among others) an installed base of fiber-optic system(s) 150. Those skilled in the art will recognize that fiber-optic system(s) 150 typically consists of many fiber-optic networks and associated subsystems which often span thousands of miles. In addition, those skilled in the art will further appreciate that fiber-optic system(s) 150 often will include miles of fiber-optic cable (e.g., which has been buried underground). Consequently, it is recognized in the art that modifying of fiber-optic system(s) 150 is, from both a technical and financial perspective, an expensive proposition which is not ordinarily undertaken unless absolutely necessary.
10
15

The transmission rate for optical channels 115(1)-(N), singly or in the aggregate, is typically limited by the available bandwidth, as in any communications system. In a network such as that depicted in Fig. 1, the chief limitation on bandwidth, and so transmission rate, is the capacity of the underlying optical communications system (e.g., fiber-optic system(s) 150), which is, in turn, limited by
20 the physical characteristics of the optical components used in the underlying optical communications system. Such physical characteristics include the frequency of the optical carrier(s), their spacing, the transmission characteristics of the optical fiber(s), the distance between network elements and other such parameters. Typically, the bandwidth available to a datastream, and so its maximum transmission rate, is a
25 function of the frequency (or, conversely, wavelength) of the optical carrier, and the distance that optical carrier must traverse.
30

Relatively recently, the data communications speeds of network components operating in the electrical domain have begun to substantially exceed the data communications speeds of network components operating in the optical domain. This situation is illustrated in Fig. 2.

5 Fig. 2, illustrates a network substantially analogous to that shown in Fig. 1, which includes network elements 200 and 201. Network elements 200 and 201 include protocol processors 200 and 202 and their respectively associated high-speed datastreams 204 and 206. This information is carried by one of optical channels 115(1)-(N). It will be noted that only high-speed datastreams 204 and 206 are
10 depicted in Fig. 2. High-speed datastreams 204 and 206 correspond to only one of high-speed datastreams 104(1)-(N) and 106(1)-(N) in order to simplify the following discussions. However, in Fig. 2, the communications speed (e.g., data rate) of protocol processors 200 and 202, and so high-speed datastreams 204 and 206, exceeds the physical capabilities of the underlying network (e.g., fiber-optic system(s) 150). In other words, the electrical-domain components have transmission rates in excess of the maximum transmission rate of some or all of the optical-domain network components in fiber-optic system(s) 150. Thus, the physical characteristics of the underlying optical network limit the data rate of high-speed datastreams 204 and 206, and the extra capacity of protocol processors 200 and 202 goes unused.

15 20 As noted, it is recognized in the art that modifying fiber-optic system(s) 150 is difficult from a technical standpoint and expensive from a financial standpoint. Those skilled in the art will appreciate that the situation illustrated in Fig. 2 is seen as requiring modification of fiber-optic system(s) 150. Accordingly, most existing solutions to such a problem concentrate on partially reconstructing the underlying
25 fiber-optic systems such that the reconstructed network can support the higher data transmission rates of protocol processors 200 and 202. Fig. 3 and 4 illustrate such solutions.

30 Fig. 3 illustrates one approach to the problems experienced by the network depicted in Fig. 2 by providing fiber-optic system(s) 300. In Fig. 3, as in Fig. 2, high-speed datastreams 204 and 206 operate at higher transmission rates than the

corresponding ones of high-speed datastreams 104(1)-(N) and 106(1)-(N). Because, in the given technology, information transmitted at higher transmission rates cannot be transmitted as far as information transmitted at relatively lower transmission rates, optical fiber(s) 120 are divided into optical fiber(s) 310(1)-(N+1) to allow placement of repeaters 320(1)-(N). Optical fiber(s) 310(1)-(N+1) are of lengths d_1 through d_{N+1} , respectively, each of which is shorter than length d , so that the optical carriers operating at higher transmission rates need not be transmitted as far as those in Fig. 2. Repeaters 320(1)-(N) regenerate the optical signals corresponding to high-speed datastreams 204 and 206, which are depicted in Fig. 3 as being transported over optical channels 330(1)-(N+1). Due to their shorter lengths and the regeneration that is performed by repeaters 320(1)-(N), each of optical fiber(s) 310(1)-(N+1) is capable of supporting higher-frequency (i.e., shorter wavelength) optical carriers (e.g., optical channels 330(1)-(N+1)) than optical fiber(s) 120. This enables fiber-optic system(s) 300 to support higher-speed datastreams than fiber-optic system(s) 150.

The approach depicted in Fig. 3 is an expensive alternative, from a financial standpoint, in that it involves manually restructuring large portions of fiber-optic system(s) 150 to create optical fiber(s) 310(1)-(N+1), as well as the purchase, installation, management and maintenance of repeaters 320(1)-(N). The solution depicted in Fig. 3 is also involves greater technical complexity, in that such a solution increases management and maintenance issues associated with the larger number of smaller fiber-optic segments (e.g., optical fiber(s) 310(1)-(N+1)), as well as the management and maintenance associated with repeaters 320(1)-(N).

Fig. 4 illustrates another approach, in which higher-speed components are used. To increase transmission rates within fiber-optic system(s) 150, improved optical fibers and associated subsystems are installed to replace some or all of the existing optical fibers and associated subsystems of fiber-optic system(s) 150, thus resulting in fiber-optic system(s) 400. For example, fiber-optic system(s) 400 are able to handle the higher transmission rates necessitated by high-speed datastreams 204 and 206 as a result of using improved optical fiber (depicted in Fig. 4 as optical fiber(s) 410). Such new fibers, as well as associated subsystems are designed to support communications over the required distance (e.g., d) and yet still accommodate

higher-frequency (i.e., shorter wavelength) optical carriers sufficient to support the requisite higher transmission rates. Such higher-frequency optical carriers are depicted in Fig. 4 as optical channels 420.

Unfortunately, this solution is expensive from both a technological and

- 5 financial standpoint, in that such a solution often involves extensive research and development efforts (including financial support therefor) in order to create the new optical technologies – a venture which may or may not prove successful. Moreover, this solution also involves the manual reconstruction of the underlying fiber-optic network, requiring the installation of the new optical fibers and subsystems.

10 With respect to the approaches depicted in Figs. 3 and 4, it will be apparent to those of skill in the art that, subsequent to their implementations, a large installed base of fiber-optic systems having an upper limit of transmission limited by the fastest optical channel available will still exist, albeit with a higher upper limit than that of the original fiber-optic system(s). Accordingly, when and if the speed of the protocol processors operating in the electrical domain again exceed this new upper limit, solutions analogous to those depicted in Figs. 3 and 4 will once again require implementation.

15 Unfortunately, the approaches depicted in Figs. 3 and 4 are financially taxing and technologically complex, as noted. In addition, those skilled in the art will

- 20 recognize that, in the context of such networks, a problems analogous to that and described with regard to Fig. 2 will likely arise again. In light of this, it is apparent that a need exists in the art for a method and system which will solve those problems illustrated by the network of Fig. 2, and others, without requiring such expensive, labor-intensive and complex solutions.

25 What is therefore needed is a simple, inexpensive technique to transport high-bandwidth datastreams across a network. Such a technique should be applicable to optical networks, and preferably support long-haul optical networks in particular.

SUMMARY OF THE INVENTION

In one embodiment of the present invention, a method for transporting information over a network is disclosed. The method includes decomposing a datastream into a number of sub-streams, and communicating the sub-streams between a first network element and a second network element of the network by transporting each one of the sub-streams over one of a number of channels. The bandwidth of the datastream is greater than a bandwidth of any one of the channels.

In another embodiment of the present invention, a method for receiving information transported over a network is disclosed. The method includes receiving a number of sub-streams and assembling the sub-streams into a reconstructed datastream. The sub-streams are created by decomposing a datastream into the sub-streams. Each of the sub-streams is transported over the network on a corresponding one of a number of channels. A bandwidth of the datastream is greater than a bandwidth of any one of the channels.

In yet another embodiment of the present invention, an apparatus for transporting information over a network is disclosed. The apparatus includes a first sub-stream management device. The first sub-stream management device includes an input configured to receive a datastream and a number of outputs. Each of the outputs is configured to output one of a number of sub-streams. Each of the sub-streams is transported over the network on a corresponding one of a number of channels. A bandwidth of the datastream is greater than a bandwidth of any one of the channels.

In still another embodiment of the present invention, an apparatus for transporting information over a network is disclosed. The apparatus includes first sub-stream management device. The first sub-stream management device includes an output configured to output a reconstructed datastream and a number of inputs. Each of the inputs is configured to receive one of a number of sub-streams, which are created by decomposing a datastream into the sub-streams. Each of the sub-streams is transported over the network on a corresponding one of a number of channels. A bandwidth of the datastream is greater than a bandwidth of any one of the channels.

The foregoing is a summary and thus contains, by necessity, simplifications, generalizations and omissions of detail; consequently, those skilled in the art will appreciate that the summary is illustrative only and is not intended to be in any way limiting. As will also be apparent to one of skill in the art, the operations disclosed 5 herein may be implemented in a number of ways, and such changes and modifications may be made without departing from this invention and its broader aspects. Other aspects, inventive features, and advantages of the present invention, as defined solely by the claims, will become apparent in the non-limiting detailed description set forth below.

10 **BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention may be better understood, and its numerous objects, features, and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

Fig. 1 is a block diagram illustrating an optical communications network.

15 Fig. 2 is a block diagram illustrating an optical communications network similar to that of Fig. 1.

Fig. 3 is a block diagram illustrating an optical communications network employing repeaters.

20 Fig. 4 is a block diagram illustrating an optical communications network employing higher-speed optical components.

Fig. 5 is a block diagram illustrating an optical communications network according to embodiments of the present invention.

Fig. 6 is a block diagram illustrating another optical communications network according to embodiments of the present invention.

25 Fig. 7 is a block diagram illustrating another optical communications network according to embodiments of the present invention.

Fig. 8 is a flow diagram illustrating a process according to an embodiment of the present invention.

The use of the same reference symbols in different drawings indicates similar or identical items.

5 **DETAILED DESCRIPTION OF THE INVENTION**

The following is intended to provide a detailed description of an example of the invention and should not be taken to be limiting of the invention itself. Rather, any number of variations may fall within the scope of the invention which is defined in the claims following the description.

10 **Introduction**

Embodiments of the present invention provide a method and apparatus for transporting high-bandwidth (high-speed) datastreams over a network. As noted, this is of particular concern in optical networks, where the advance of technology may not keep pace with the ever-increasing bandwidth requirements of today's (and tomorrow's) high-bandwidth applications. From a physical perspective, this challenge is particularly daunting when transporting such datastreams over long-haul optical networks.

15 Embodiments of the present invention address the need for increased bandwidth in current networks by decomposing each high-speed datastream into multiple sub-streams, transporting the sub-streams across the network and then re-assembling the sub-streams at the high-speed datastream's destination. Because the sub-streams' data rates are only a fraction of that of the high-speed datastream, embodiments of the present invention can provide such capabilities using existing (or available) network infrastructure (e.g., fiber-optic system(s) 150). Thus, by 20 decomposing a high-speed datastream for transport, few, if any, changes need be made to the underlying network, avoiding potentially expensive and complex re-engineering of the existing network and allowing higher transmission rates over the given distance without the use of repeaters or other new optical infrastructure.

An Example Network Architecture

Fig. 5 is a block diagram illustrating a system substantially analogous to that shown in Fig. 2. However, the system of Fig. 5 remedies certain of the problems experienced in the system of Fig. 2 via the use of techniques according to
5 embodiments of the present invention. As noted, each high-speed datastream is decomposed into multiple sub-streams, which are then transported across the network over separate optical channels. Once the sub-streams reach the high-speed datastream's destination, the sub-streams are re-assembled. Because the bandwidth of each sub-stream are less than that of the original high-speed datastream, the
10 bandwidth requirements that each sub-stream places on its corresponding optical channel are reduced. In fact, if a sufficient number of sub-streams are employed, the bandwidth requirements of each sub-stream can be reduced to the point where existing optical channels are able to carry one or more such sub-streams.

Referring to Fig. 5, and as similarly depicted in Figs. 1 and 2, a network 500 is illustrated in which fiber-optic system(s) 150 are employed to allow communications between network elements 510 and 520. As in Fig. 2, network elements 510 and 520 include protocol processors 202 and 203, which provide a standard protocol stack that ensures that the information being transported is appropriately processed and routed. However, as noted in regard to Fig. 2, protocol processors 202 and 203 are capable of operating at higher data rates than protocol processors 102 and 103, and thus handle high-speed datastreams 204 and 206, which themselves have greater data rates than the corresponding ones of high-speed datastreams 104(1)-(N) and 106(1)-(N).

In contrast to other approaches, network elements 510 and 520 include sub-stream management devices 530 and 540. Sub-stream management devices 530 and 540 are capable of decomposing high-speed datastream 204 into a number of sub-streams (depicted in Fig. 5 as sub-streams 550(1)-(N)). Each of sub-streams 550(1)-(N) can then be transported across fiber-optic system(s) 150. Once transported thusly, the resulting sub-streams (which are depicted in Fig. 5 as sub-streams 560(1)-(N)) are re-assembled by sub-stream management device 540, emerging as a reconstructed

datastream, high-speed datastream 206. As before, high-speed datastream 206 is then processed by protocol processors 203.

In one embodiment, no changes to fiber-optic system(s) 150 are required or made. In such embodiments, sub-streams 550(1)-(N) correspond directly to high-speed datastreams 104(1)-(N), and so are able to traverse fiber-optic system(s) 150 in the same manner. That being the case, electrical-optical converter 112 receives sub-streams 550(1)-(N) from sub-stream management device 530 at port 106 and converts sub-streams 550(1)-(N) from the electrical domain to the optical domain, appearing at optical port group 116, which interfaces with optical fiber(s) 120, as before. The sub-streams are then transported across optical fiber(s) 120 within optical channels 115(1)-(N), to optical port group 118. Electrical-optical converter 114 then converts the sub-streams from the optical domain to the electrical domain, resulting in sub-streams 560(1)-(N) at port 110. Sub-stream management device 540 then assembles sub-streams 560(1)-(N) into high-speed datastream 206, which is then processed by protocol processors 203. It will be noted that sub-stream management devices 530 and 540 are shown separately in Fig. 5A for the sake of clarity. It will be apparent to one of skill in the art that sub-stream management devices 530 and 540 can be integrated into either of protocol processors 202 and 203, or electrical-optical converters 112 and 114, respectively, with no loss of generality.

As noted, those skilled in the art will recognize that fiber-optic system(s) 150 typically consist of many fiber-optic networks and associated subsystems which often span thousands of miles. In addition, those skilled in the art will further appreciate that fiber-optic system(s) 150 often will include miles of fiber-optic cable (e.g., which has been buried underground). Consequently, it is recognized in the art that modifying of fiber-optic system(s) 150 is, both a technically complex and financially taxing proposition which is not ordinarily undertaken. Thus, embodiments of the present invention allow the use of existing infrastructure (e.g., fiber-optic system(s) 150) to support higher data rates, avoiding the aforementioned complexities and expense.

Fig. 6 is a block diagram illustrating a network 600 which is substantially analogous to that shown in Fig. 5, but shows a more specific implementation of sub-stream management devices 530 and 540. As before, network 600 includes fiber-optic system(s) 150 that allow communications between network elements 610 and 620. In network 600, sub-stream management devices 530 and 540 are implemented as super-channel framing and management devices 630 and 640, which have access to and control over the super-channel. Such super-channel framing and management devices are discussed in detail in the Provisional Patent Application entitled, "METHOD AND APPARATUS FOR WAVELENGTH CONCATENATED CHANNEL FRAMING," as previously included by reference herein. The aggregate collection of N sub-channels supportive of a high-speed datastream such as high-speed datastream 204 or 206 is referred to herein as a "super-channel."

In this embodiment, each super-channel framing and management device splits its associated electrical-domain high-speed datastream (e.g., high-speed datastreams 204 and 206) into a series of N data channels (where N is a positive integer greater than one), where each of the N data channels has a data transmission rate that can be accommodated by existing optical channels (e.g., optical channels 115(1)-(N)) within fiber-optic system(s) 150. Preferably, each super-channel framing and management device (e.g., super-channel framing and management device 630 or 640) functions substantially transparently to protocol processors 202 and 203, as well as being transparent to fiber-optic system(s) 150. Thus, the protocol processors and underlying fiber-optic system(s) should function in substantially the same manner as in existing networks, with sub-channels able to be transported over optical channels already provided by underlying fiber-optic system(s). It is also desirable to ensure that such super-channel framing and management devices have the ability to provide varying levels of reliability of transmission for various types of transmitted data.

From a more quantifiable perspective, a high-speed datastream might have a data rate of D_{HS} . This data rate can also be related to a frequency F_{HS} , with a bandwidth $\lambda_{HS} = 1 / F_{HS}$. This is the data rate of the super-channel corresponding to the high-speed datastream. In the situation posited here, the bandwidth available over any one (or at least, a given) optical channel, λ_{OC} , is less than the bandwidth of the

high-speed datastream, λ_{HS} , or $\lambda_{OC} < \lambda_{HS}$. However, when converted into a super-channel (still with a bandwidth $\lambda_{SC} = \lambda_{HS}$) having multiple sub-channels, the bandwidth of a given sub-channel, λ_{SC} , is made to be equal to or less than the bandwidth available over the corresponding optical channel, λ_{OC} , or $\lambda_{SC} \leq \lambda_{OC}$. Thus,

- 5 by decomposing a high-speed datastream (and so super-channel) into sub-streams (sub-channels), the data within the high-speed datastream can be transported across fiber-optic system(s) 150. Because the sub-channels can be treated as a super-channel (i.e., the sub-channels can be treated as an entity by super-channel framing and management devices), management of the sub-channels is simplified.

10 As with sub-stream management devices 530 and 540, super-channel framing and management devices 630 and 640 are, in certain embodiments, able to convert high-speed datastream 204 into sub-channels 650(1)-(N) (which can also be viewed as a super-channel 655 that corresponds to high-speed datastream 204), which correspond to high-speed datastreams 104(1)-(N). These data streams are, as before, able to traverse fiber-optic system(s) 150 over optical channels 115(1)-(N). Once transported, these datastreams appear at electrical-optical converter 114 as sub-channels 660(1)-(N) (which can also be viewed as a super-channel 665 that corresponds to high-speed datastream 206). Super-channel framing and management device 640 takes in sub-channels 660(1)-(N), re-assembling the sub-channels into high-speed datastream 206. The deployment of super-channel framing and management devices 630 and 640 thus allows fiber-optic system(s) 150 to handle high-speed datastreams 204 and 206 without the reconstruction of fiber-optic system(s) 150, avoiding the expense and complexity normally associated with doing so. In a manner similar to that previous noted, and for ease of illustration, super-
25 channel framing and management devices 630 and 640 are shown interposed between protocol processors 202 and 203, and electrical-optical converters 112 and 114, respectively. In practice, super-channel framing and management devices 630 and 640 will ordinarily be embedded within or distributed between such protocol processors and/or electrical-optical converters. In such cases, the protocol processors
30 and/or electrical-optical converters involved may be modified to some degree, in accordance with the teachings herein.

Fig. 7 is a block diagram illustrating a system substantially analogous to that shown in Fig. 6, but with super-channel framing and management devices 630 and 640 receiving high-speed datastreams 710 and 720. High-speed datastreams 710 and 720 contain, and super-channel framing and management devices 630 and 640 have access to and control over two super-channels (depicted in Fig. 7 as super-channels 730, 735, 740 and 745) and at least one datastream/channel that remains unused by either of the super-channels (depicted in Fig. 7 as a channel 750 and a channel 755).

Fig. 7 illustrates that each of super-channel framing and management devices 630 and 640 handles respective ones of super-channels 730 and 740, each of which is substantially analogous to the super-channels described in relation to Fig. 6. Super-channel 730 (super-channel 740) can be composed of, for example, sub-channels 760(1)-(M) (sub-channels 770(1)-(M)) (where M is some integer greater than 1), where each of sub-channels 760(1)-(M) (sub-channels 770(1)-(M)) is carried by an existing optical channel of fiber-optic system(s) 150 (e.g., one of optical channels 115(1)-(N)). Further shown is that each of super-channel framing and management devices 630 and 640 also handles, respectively, at least one additional super-channel (depicted in Fig. 7 as super-channels 740 and 745). Super-channels 740 and 745 are composed of sub-channels 760(M+1)-(N) (sub-channels 770(M+1)-(N)) (where M and N are some integer greater than 1). As with sub-channels 760(1)-(M) and 770(1)-(M), each of sub-channels 760(M+1)-(N) and 770(M+1)-(N) is carried by an existing optical channel of fiber-optic system(s) 150 (e.g., one of optical channels 115(1)-(N)). Each of super-channel framing and management devices 630 and 640 also has access to at least one additional existing channel (channels 750 and 755) of fiber-optic system(s) 150 which is transported across one of optical channels 115(1)-(N) that is not currently being utilized to carry a super-channel's traffic.

Fig. 8 is a flow diagram illustrating a process according to embodiments of the present invention, in which a high-speed datastream is transported across a network having a number of channels (e.g., optical channels), none of which, taken alone, is able to provide sufficient bandwidth to support the high-speed datastream. The process begins with the reception of the high-speed datastream (step 800). The high-speed datastream (e.g., high-speed datastream 204) might be, for example, received

from a protocol processor such as protocol processor 202. The high-speed datastream is then decomposed into a number of sub-streams (step 810). This division can, for example, be performed by a sub-stream management device such as sub-stream management device 530. It will be noted, however, that the high-speed datastream

- 5 can be decomposed prior to processing by protocol processor, should that be preferable in the given situation. Each of the sub-streams should have a bandwidth that is equal to or less than the corresponding one of the network's channels, over which the given sub-stream is to be transported. It will be noted that, however, one or more sub-streams may have a bandwidth greater than its corresponding channel, but
10 be compressed to meet the bandwidth requirements of the given channel.

The high-speed datastream can be decomposed into sub-streams in any one of a number of ways. For example, a simple round-robin technique may be employed, where a portion of the high-speed datastream is periodically placed in one of a number of queues, each corresponding to one of the channels. A variation of this concept that includes framing and other mechanisms is discussed in the Provisional Patent Application entitled, "METHOD AND APPARATUS FOR WAVELENGTH CONCATENATED CHANNEL FRAMING," as previously included by reference herein.

Once decomposed into sub-streams, the high-speed datastream is transported
20 across the network by transporting each of the (possibly compressed) sub-streams over a corresponding channel (step 820), such as one of optical channels 115(1)-(N). After being transported across the network thusly, the sub-streams are re-assembled at the high-speed datastream's destination (e.g., by a process that is the mirror-image of that used to decompose the high-speed datastream) (step 830). This can be accomplished,
25 for example, using a sub-stream management device such as sub-stream management device 540. The high-speed datastream (e.g., high-speed datastream 206), thus re-assembled, can now be provided for further processing at the destination (step 840). This might be, for example, processing by a protocol processor such as protocol processor 203.

- As noted, Fig. 8 depicts a flow diagram illustrating a process according to an embodiment of the present invention. It is appreciated that operations discussed herein may consist of directly entered commands by a computer system user or by steps executed by application specific hardware modules, but the preferred embodiment includes steps executed by software modules. The functionality of steps referred to herein may correspond to the functionality of modules or portions of modules.

The operations referred to herein may be modules or portions of modules (e.g., software, firmware or hardware modules). For example, although the described embodiment includes software modules and/or includes manually entered user commands, the various example modules may be application specific hardware modules. The software modules discussed herein may include script, batch or other executable files, or combinations and/or portions of such files. The software modules may include a computer program or subroutines thereof encoded on computer-readable media.

Additionally, those skilled in the art will recognize that the boundaries between modules are merely illustrative and alternative embodiments may merge modules or impose an alternative decomposition of functionality of modules. For example, the modules discussed herein may be decomposed into submodules to be executed as multiple computer processes, and, optionally, on multiple computers. Moreover, alternative embodiments may combine multiple instances of a particular module or submodule. Furthermore, those skilled in the art will recognize that the operations described in example embodiment are for illustration only. Operations may be combined or the functionality of the operations may be distributed in additional operations in accordance with the invention.

Alternatively, such actions may be embodied in the structure of circuitry that implements such functionality, such as the micro-code of a complex instruction set computer (CISC), firmware programmed into programmable or erasable/programmable devices, the configuration of a field-programmable gate array

(FPGA), the design of a gate array or full-custom application-specific integrated circuit (ASIC), or the like.

Each of the blocks of the flow diagram may be executed by a module (e.g., a software module) or a portion of a module or a computer system user using, for example, a computer system such as the storage router previously mentioned, or a similar network element, as well as a computer system such as computer system 210. Thus, the above described method, the operations thereof and modules therefor may be executed on a computer system configured to execute the operations of the method and/or may be executed from computer-readable media. The method may be embodied in a machine-readable and/or computer-readable medium for configuring a computer system to execute the method. Thus, the software modules may be stored within and/or transmitted to a computer system memory to configure the computer system to perform the functions of the module.

Such a computer system normally processes information according to a program (a list of internally stored instructions such as a particular application program and/or an operating system) and produces resultant output information via I/O devices. A computer process typically includes an executing (running) program or portion of a program, current program values and state information, and the resources used by the operating system to manage the execution of the process. A parent process may spawn other, child processes to help perform the overall functionality of the parent process. Because the parent process specifically spawns the child processes to perform a portion of the overall functionality of the parent process, the functions performed by child processes (and grandchild processes, etc.) may sometimes be described as being performed by the parent process.

Such a computer system typically includes multiple computer processes executing "concurrently." Often, a computer system includes a single processing unit which is capable of supporting many active processes alternately. Although multiple processes may appear to be executing concurrently, at any given point in time only one process is actually executed by the single processing unit. By rapidly changing the process executing, a computer system gives the appearance of concurrent process

execution. The ability of a computer system to multiplex the computer system's resources among multiple processes in various stages of execution is called multitasking. Systems with multiple processing units, which by definition can support true concurrent processing, are called multiprocessing systems. Active processes are 5 often referred to as executing concurrently when such processes are executed in a multitasking and/or a multiprocessing environment.

The software modules described herein may be received by such a computer system, for example, from computer readable media. The computer readable media may be permanently, removably or remotely coupled to the computer system. The 10 computer readable media may non-exclusively include, for example, any number of the following: magnetic storage media including disk and tape storage media, optical storage media such as compact disk media (e.g., CD-ROM, CD-R, etc.) and digital video disk storage media, nonvolatile memory storage memory including semiconductor-based memory units such as FLASH memory, EEPROM, EPROM, ROM or application specific integrated circuits, volatile storage media including registers, buffers or caches, main memory, RAM, and the like, and data transmission media including computer network, point-to-point telecommunication, and carrier wave transmission media. In a UNIX-based embodiment, the software modules may be embodied in a file which may be a device, a terminal, a local or remote file, a 15 socket, a network connection, a signal, or other expedient of communication or state change. Other new and various types of computer-readable media may be used to store and/or transmit the software modules discussed herein.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings 20 herein, changes and modifications may be made without departing from this invention and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of this invention. Furthermore, it is to be understood that the invention is solely defined by the appended claims.